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Acquisition of serial order in speech production: An ultrasound study of typical 4-year-old Canadian French children.

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This study investigates the process by which young children learn to produce sequences of speech sounds in an adult-like manner. Learning to produce speech sounds requires precise motor control of several oro-facial muscles and the ability to link these motor activations both with articulatory movements in the vocal tract(via somatosensory feedback) and with acoustic realizations (via auditory feedback). During this first learning phase, a number of agonistic and antagonistic muscle synergisms aredeveloped. The acquisition of serial order in speech production implies, in addition to these skills,the ability to plan and execute sequences of motor commands with fine temporal coordination.

In line with theories of optimal motor control, gesture planning is assumed to make use of neural representations (internal models) of the motor system in order to minimize some measure of cost in producing sequences of movements. In this framework, the efficiency of speech planning is considered to reflect the maturity of these neural representations.

It is well-established that normally developing children above a certain age are able to produce all the sounds of their native language distinctively.However, we hypothesize that these children are not able to organize gesturestemporally and spatially in an adult-like manner when producing sequences of speech sounds, reflecting a lack of maturity of motor control.

To test this hypothesis, we conducted an experiment in which we recorded acoustic and ultrasound data (collected in the mid-sagittal plane) from twenty four-year-old children and from ten adults aged 19-30 for comparison. Participants had to recall, plan and pronounce utterances in an experiment designed as a puppet game in which puppet names were isolated vowels and vowel-consonant-vowel sequences. We obtained tongue-movement recordings withthe Haskins Optically Corrected Ultrasound System (HOCUS), which uses optical tracking of infrared emitting diodes, positioned both on the ultrasound probe and on the head of the participant to provide a representation of the data corrected for probe movement and aligned with palatal hard structure.

In agreement with numerous studies ofarm motor control and studies of speech production development, we found more token-to-token variability in young children than in adults for isolated soundsin both the articulatory and acoustic domains.For speech sequences, also in both domains, results indicate that children display less

anticipatory coarticulation (i.e., less influence of an upcoming sound on the current one). Based on these findings, we infer that despite their ability to reach the production targets ina3-sound sequence, four-year-old childrenare not able to take advantage of perceptually licensed variability of a given speech sound in anticipating forthcoming gestures. According to our theoretical framework, this finding reflects a lack of maturity of children'sneural models ofthe speech production mechanism.